

UCRL- 96819
PREPRINT

3-D Hybrid PIC Code to Model the Tilt
Mode in FRCs*

E.J. Horowitz
D.E. Shumaker

CIRCULATION COPY
SUBJECT TO RECALL
IN TWO WEEKS

This Paper was Prepared for Submittal to
8th Compact Toroid Symposium
June 4-5, 1987
College Park, Maryland

June 1987

Lawrence
Livermore
National
Laboratory

This is a preprint of a paper intended for publication in a journal or proceedings. Since changes may be made before publication, this preprint is made available with the understanding that it will not be cited or reproduced without the permission of the author.

DISCLAIMER

This document was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor the University of California nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial products, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement recommendation, or favoring of the United States Government or the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or the University of California, and shall not be used for advertising or product endorsement purposes.

3-D Hybrid PIC Code to Model the Tilt Mode in FRCs*

E.J. Horowitz and D.E. Shumaker

National Magnetic Fusion Energy Computer Center

Lawrence Livermore National Laboratory

Livermore, California 94550

The results from QN3D are presented. QN3D is a 3-dimensional hybrid particle-in-cell code designed to run efficiently on the Cray-2 Multiprocessor. The chief application has been to the tilt mode instability in FRCs.

QN3D accepts as input, the magnetic field, the ion particle density and the ion temperature on a two-dimensional r-z grid. These quantities are interpolated to the rest of the cartesian grid under the assumption of azimuthal symmetry. The particles are initialized with random numbers chosen according to the particle distributions input from the equilibrium code. The runs done here used equilibria computed by EQV, a kinetic equilibrium code developed by Dan Shumaker.

In general we would assume that if the plasma containment vessel were far from the plasma boundary then the shape of the vessel would be of little consequence [1]. However, to facilitate modelling devices with passive mirrors we actually modelled the cylindrical wall as closely as possible.

We expect the tilt mode to be unstable when the ion gyroradius becomes small with respect to the size of the plasma. A convenient measure of this relative size is s , which is a measure of the number of ion gyroradii between the o-point and the separatrix. Analytically [2]

$$s \doteq \int_R^{r_s} \frac{r}{r_s} \frac{dr}{\rho_i(r)},$$

where R is the o-point radius, r_s is the separatrix radius and ρ_i is the ion gyroradius. We investigated two cases, one with $s = 1.6$ and another with $s = 12$.

One easy method of viewing plasma behavior is to plot contours of constant particle density. This showed very clearly that one case tilted while the other did not (see figure 1).

Note that the tilt mode instability observed here grew out of noise introduced by the random nature of the particle initialization. No initial perturbation was employed to help the plasma develop the tilt.

For a quantitative diagnostic, we simulated an experimental method suggested by Michel Tuszewski of the Los Alamos National Laboratory. He suggested that we measure the Faraday rotation of a light beam shot through the plasma. The Faraday rotation of such a beam is proportional to the integral of the density multiplied by the magnetic field [3], i.e.

$$\Theta_F \propto \int n_i \mathbf{B} \cdot d\mathbf{l}, \quad (1)$$

where the integral is along the beam. From symmetry, it is clear that Θ_F is initially zero in an FRC. However, as the tilt mode develops, some rotation should be noticeable. In fact, we should be able to recognize the tilt mode by the signature in a plot of Θ_F as a function of z (figure 2).

In order to pick the tilt mode signature out of the noise we fitted the simulated Faraday rotation data to a polynomial with the same signature. In particular, we used a least-squares fit to

$$f_x(z) = (Az^4 - Bz^8)e^{-(z/L)^4}$$

where L is predetermined and A and B are found by the fitting procedure. f_x is the polynomial that fits the data found from the Faraday rotation diagnostic done in the x - z plane. A similar function, $f_y(z)$, was found for the y - z plane data. To get a magnitude from these functions we simply integrated the sum of the square of these functions, and then took the root, i.e.

$$|\Theta_F| \doteq \left[\int_{z_{min}}^{z_{max}} (f_x^2(z) + f_y^2(z)) dz \right]^{1/2}.$$

$|\Theta_F|$ gives us a magnitude as function of time from which we can get a growth rate. Again, The results are quite clear. The high- s case shows the tilt growing with a growth rate close to MHD predictions ($\gamma = 1.24\gamma_{MHD}$). The low- s case shows only slight growth if any at all ($\gamma = .07\gamma_{MHD}$). Note that comparing the magnitudes of these numbers is not possible since in the density and magnetic fields are orders of magnitude different.

Our results compare favorably with preliminary results from Barnes, et al. [4] (see figure 3). We would not expect exact agreement since their equilibria are different and they are measuring the displacement of the flux surfaces rather than the Faraday rotation. However, the general agreement is very encouraging.

Quite fortunately, we have been able to give strong credence to our initial hypothesis that the tilt mode will exist in regimes of higher s . This result, by itself, is important for those planning to build larger FRC experiments. But, in addition, QN3D has a major advantage in that it should be able to model the nonlinear regime of the tilt mode which will be even more crucial to the future of FRC experiments.

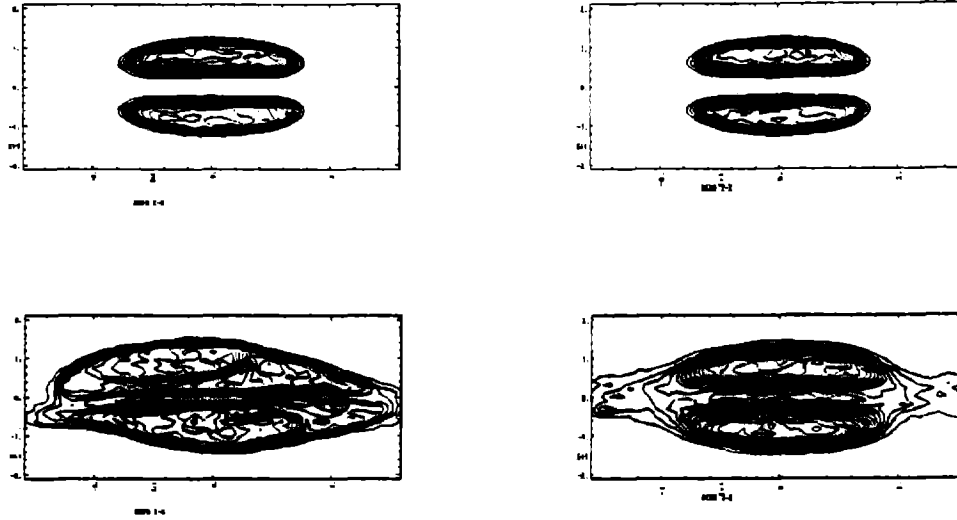


Figure 1: Surfaces of Constant Density

Top: $0\mu s$ *Bottom:* $3\mu s$
Left: $s = 12$ *Right:* $s = 1.6$

References

- [1] D.S. Harned, *J. Comput. Phys.* **47** (1982), 452.
- [2] J.T. Slough, A.L. Hoffman, R.D. Milroy, D.G. Harding and L.C. Steinhauer, *Nuclear Fusion* **24** (1984), 1537.
- [3] D.E. Shumaker, "Plasma Physics", class notes for UCD DAS 280C, 1985.
- [4] D.C. Barnes, J.L. Schwarzmeier, H.R. Lewis and C.E. Seyler, *Phys. Fluids* **29** (1986), 2616.

*This work was performed under the auspices of the United States Department of Energy by the Lawrence Livermore National Laboratory under contract W-7405-ENG-48.

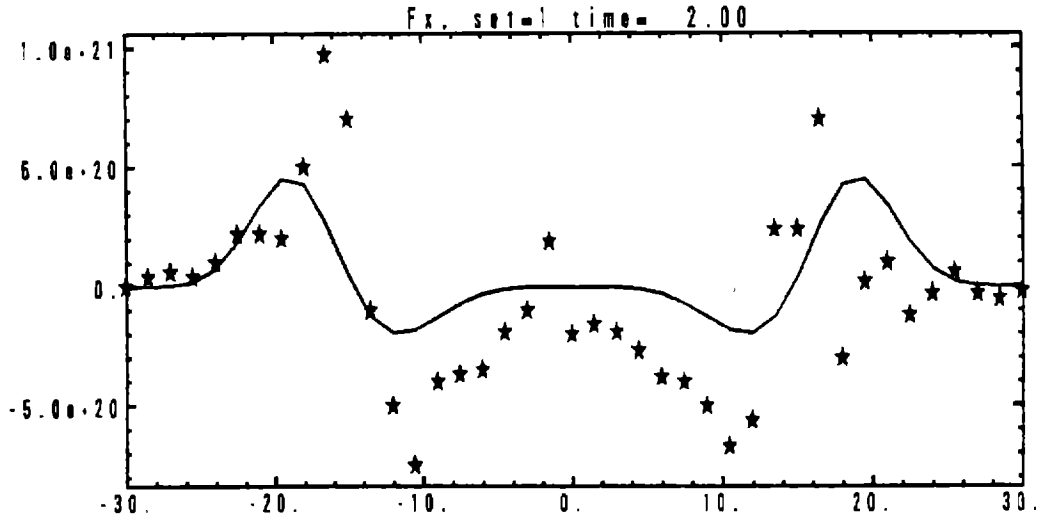


Figure 2: Expected Tilt Mode Signature from Faraday Rotation Diagnostic Θ_F is plotted as a function of z . The stars indicate the simulation results and the curve is the polynomial fit.

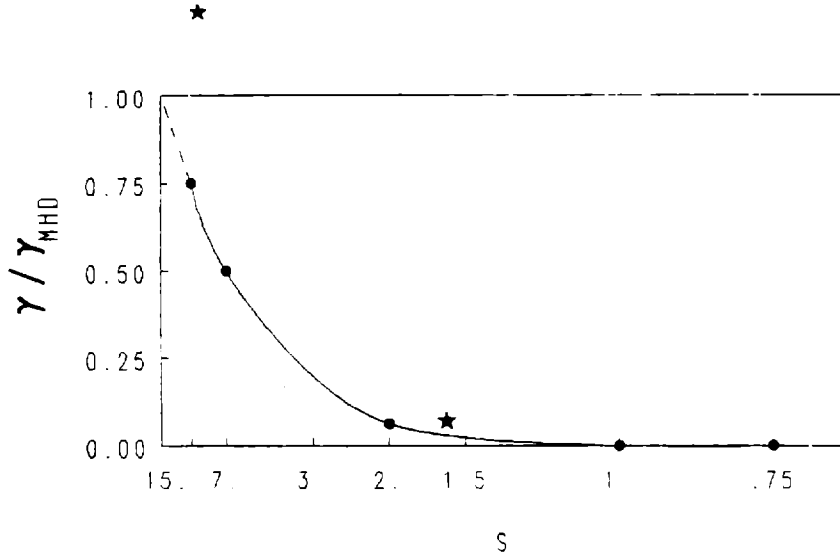


Figure 3: Barnes' Results
This figure is from the *Physics of Fluids* 29, August 1986. The stars indicate our results. Used with permission of the authors and the American Institute of Physics. © Copyright 1986 AIP